Notes on the Rotation Period of Venus. By E. M. Antoniadi.

(*Communicated by Capt. W. Noble.*)

The question of the rotation period of *Venus* is one to which the reply has eluded many a distinguished astronomer. Nor is the reason of the failures far to seek. The determination is in itself impossible by ordinary visual methods on account of the formidable diffusion of light by the planet's atmosphere, and until the day arrives when the Doppler-Fizeau principle can be successfully applied to the limb of *Venus*, we may justly display scepticism as to the value of current rotation periods.

The first attempt to determine the rotation period was made by Dominique Cassini in 1666–1667. Cassini considered the spots to be animated by a motion either of libration or rotation, having a period of less than 24 *hours*, round an axis almost coinciding with the plane of the planet's orbit.

Bianchini, who affirms that he had seen *Venus* rotate (1726–1728), fixed the rotation period as 24 *days* 8 *hours*. The axis, he considered, formed an angle of only 15° with the orbital plane.

Influenced by Jacques Cassini's ideas (as shown by Schiaparelli), the fanciful Schrœter found a period of 23 *hours* 20 *minutes* 59·04 *seconds*, while not less biassed must have been Fritsch, in giving, from *four* days' observation, the period as 23 *hours* 22 *minutes*.

Never did scientists, however, indulge more freely in illusions than when the Jesuits of the Roman College undertook, in 1839, under De Vico's direction, the determination of the planet's rotation period. Eleven thousand micrometrical measures of spots taken by Palomba, with unprecedented zeal, gave the value of $23^{h}\ 21^{m}\ 21^{s}{\cdot}9345$.

The honour of demolishing these fanciful results belongs to Professor Schiaparelli, who, in a masterly discussion of all the observations,* concluded that "the rotation of $23^{h}\ 21^{m}$ or $23^{h}\ 22^{m}$ of Jacques Cassini, Schrœter and De Vico, is the result of a series of paralogisms and vicious circles."

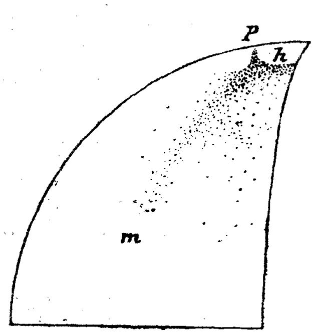

FIG. 1.

Taking as a base the immobility of some spots relatively to the terminator, the illustrious Director of the Milan Observatory

* *L'Astronomie*, 1890.

concluded that *Venus* constantly presents the same face to the Sun, or, in other words, that the rotation period coincided with the 224·7 days revolution round that luminary. Professor Schiaparelli's observations extend from 1877 December 8 to 1878 January 6. The fixed spots forming the ground work of the 224·7 days rotation may be described as follows (Fig. 1) :—

(1) An elongated dusky shading *hm* trending obliquely from the south cusp along the path of a great circle of the dichotomous or crescent phase ;

(2) A bright spot *h* near the cusp, bounded on the left by

(3) A slight diffused shading *p*.

Professor Schiaparelli notes that the spot *h* was seen by Professor Holden on 1877 December 15 ; that something like *h* and *p* was observed by Gruithuisen in 1813 and 1814, and by Vogel and Lohse in 1871.

What strikes us on an examination of these results, is an incredible cloudlessness and wonderful transparency of the atmosphere of *Venus* were these details to belong to the *body* of the planet. Seeing at once this difficulty, Professor Schiaparelli eluded it by stating that the character of these spots "seems to indicate rather atmospherical phenomena ; we consider them analogous to those which form on the surface of the Sun or *Jupiter*, and in default of something better, we will ask permission to similarly use them for determining approximately the rotation period. Cassini and Galileo did not do otherwise when studying the rotation period of *Jupiter* and the Sun."

Leaving at once aside any idea of comparison between the spots on *Jupiter* or the Sun and those of the atmosphere of *Venus*, we may say that we have every reason to believe that the latter can not be far different from the spots of our own gaseous envelope. The spots of our own atmosphere are white clouds floating in the air—a medium strongly diffusing sunlight. (We deem it quite useless to speak of volcanic smoke.) And as it is impossible to imagine clouds appearing black from above, the dusky spot *hm* can scarcely claim an objective existence. If atmospheric, it will at best be a break in a mass of clouds. But if so, is it not singular that this streak takes its position along the path of a great circle of the sphere passing through the cusps of the dichotomous or crescent phase ? Moreover, the atmosphere of *Venus* must be really very calm for a break in the clouds to remain unchanged in position for almost a month. Such constancy of form is somewhat incompatible with what we are witnessing in our aerial envelope, and dwindles into impossibility when we reflect that *Venus* receives twice as much heat as we do from the Sun, and that it is solar heat which sets the air in motion.

White cusp spots like *h* have been repeatedly seen, especially by Trouvelot. But the superior brightness of the limb, to which Sir William Herschel called attention in 1793, can satisfactorily account for them by stopping in the vicinity of the cusps the darkness along the terminator. "With regard to the cause of

this appearance" (the bright limb), says Herschel, "I may venture to ascribe it to the atmosphere of *Venus*, which, like our own, is probably replete with matter that reflects and refracts light in all directions. Therefore, on the border where we have an oblique view of it, there will be in consequence an increase of this luminous appearance."*

We should be somewhat cautious before accepting, as having objective existence, the dusky shading P. For if diffusion of light from the planet's atmosphere hides to our view all markings about the centre of the disc—where, however, the atmospheric effect is reduced to a minimum—we could not reasonably hope to define details almost on the limb itself.

Supposing, however, for one moment, that spots *h* and P are real, then analogies from the planet *Mars* would lead us to consider them as snow caps, *dimmed* in the case of *Venus* by the atmospheric effect. But the presence of snow caps on *Venus* would obviously be the *coup de grace* to the $224^{d}\cdot70$ rotation period. The snow on the illuminated hemisphere of a planet presenting always the same face to the Sun would not confine itself to a cap, but would rather distribute itself along the terminator.

It is, then, evident from our reasoning that the foundations of the $224^{d}\cdot70$ rotation period of *Venus* are delicate. The markings on which it rests would seem to be contrast effects arising from solar illumination. And we will presently show that fixity of atmospherical shadings with regard to the terminator of an inferior planet does not necessarily imply non-rotation of the body with reference to the Sun.

Scarcely had Professor Schiaparelli announced his results, than M. Perrotin, starting from the apparent immobility of a vertical shading with regard to the terminator, concluded that *Venus* rotates in a period comprised between 195 and 225 days.† M. Perrotin's drawings are of very great value. But we should point out here that he confirms Professor Schiaparelli by using a spot which, in spite of its immobility, was rejected by the great Italian himself in his determination of the planet's rotation period. In fact, M. Perrotin's vertical shading is obviously identical with the spot seen by Schrœter in 1788, and of which Professor Schiaparelli said: "The general stability of its form, which lasted for more than two months, its constant parallelism with the terminator, its almost invariable distance from the latter suggest that we have to deal here with some phenomenon of the atmosphere of *Venus*, depending much more on the Sun, and consequently on the terminator circle, than on any axis of rotation whatsoever."‡

In 1895 M. Leo Brenner announced that he had discovered the rotation period of *Venus*, which he fixed, with an accuracy equalled only by De Vico's, at $23^{h}\ 57^{m}\ 7^{s}\cdot5459$.

Meantime more than one observer was engaged in confirming

* Paper read before the Royal Society on 1793 June 13.
† *L'Astronomie*, 1890. ‡ *Ibid.* p. 328.

the long rotation. The last observations reach us from Flagstaff.

At variance with all his predecessors and successors, Mr. Percival Lowell finds the markings of *Venus* "as distinct really as those of the Moon. . . . The period of rotation coincides with the period of revolution. *This planet is a desert.*" *

The characteristic feature shown by the Flagstaff observations is a black spot in the centre of the disc from which radiate black anomalous canals, which, to judge from their appearance, would seem to have the intention of extending beyond the limb. Surely such canals, dug as they are in a gaseous envelope, have nothing whatever to do with *Venus*.

For if we know anything certain about this planet it is that it has an atmosphere (in fact, we see it when *Venus* is projected on the vicinity of the Sun), and that this atmosphere is, very probably, denser than that of *Mars*. Now, if diffusion from the rarefied aerial envelope of *Mars* does not allow us to see details about the limb, we could not reasonably hope to see canals on the limb of *Venus*, supposing we are credulous enough to believe for one second in their objective existence.

To believe in the reality of Mr. Lowell's cytherean canals means to believe that the globe of *Venus*, with its atmosphere, is imprisoned in a cage of black hoops meeting about a common diameter directed along the visual ray. Under such circumstances we cannot help considering the whole of this anomalous canal system as entirely illusory, and the central black spot as merely the "pilula" of Fontana.

Last summer I undertook at Juvisy Observatory, under M. Camille Flammarion's direction, a systematic survey of the markings of *Venus*. The observations were made in broad daylight invariably, and the planet was examined at times for three or four hours in succession. No abnormal features were seen at any time. The markings were at all times exceedingly indefinite, and always somewhat doubtful. The impression given by the general appearance of the disc was identical with Sir John Herschel's description, given in his *Outlines of Astronomy* :—"The intense lustre of its illuminated part dazzles the sight and exaggerates every imperfection of the telescope. . . . We notice in it neither mountains nor shadows, but a uniform brightness, in which sometime we may indeed fancy, or perhaps more than fancy, brighter or obscurer portions, but can seldom or never rest fully satisfied of the fact."

The colour of the planet was of a beautiful chrome yellow by day. The limb was exceedingly brilliant ; the terminator of the dichotomised disc dusky, particularly so about its central regions. From each of the cusps a diffused shading entered the disc apparently along the path of a great circle, perpendicular to the orbit of *Venus*, while midway between the terminator and the limb, somewhat nearer the former, an indefinite dusky marking

* *Bulletin de la Société Astronomique de France*, 1897.

extended occasionally from north to south, and almost parallel to the terminator. These various shadings are shown in the annexed Fig. 2.

The cusp markings, which seem to be of the same nature as Professor Schiaparelli's spot *hm* on the contrary phase, were always visible; but the vertical shading, which is analogous to

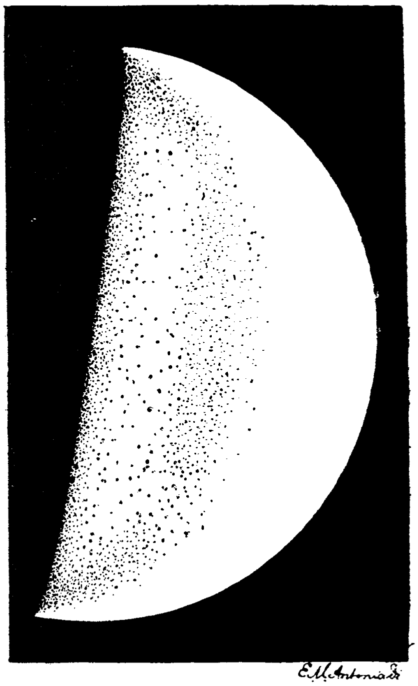

Fig. 2.

Schrœter's and M. Perrotin's streaks on the evening star apparition, had a periodical existence only. But when there, all three spots kept constantly the same positions with regard to the terminator, not the slightest trace of rotation being detected.

Obviously such markings are far too symmetrical to induce us to employ them in determining the rotation period.

Examining the causes governing the illumination of *Venus* when dichotomised, we find that such illumination obeys :—

(1) Lambert's law of the cosine.
(2) The increased brilliance towards the limb.

The simultaneous action of these two causes gives a very plausible explanation of the dusky cusp spots, from the fact that the superior luminosity of the border brightens the extremities of the duskiness along the terminator. And as the increase of brightness towards the limb, at first insignificant about the centre, becomes suddenly very marked in the immediate vicinity of the border, the luminous decrease along the terminator will be enhanced by contrast, almost to spots trending obliquely from the cusps along the path of a great circle of the sphere passing through them.

It is less easy to offer a satisfactory explanation of the vertical shading lying midway between the terminator and the limb. But we cannot consider it as having an objective existence; the more so as the same phenomenon is visible on the evening star phase of *Venus*, and we will not indulge in the wild fancies which would involve cutting the atmosphere of this planet into spherical ungulæ of alternately white and dusky material, having their common diameter at right angles to the orbital plane.

The only reasonable interpretation we can find for this marking is that of an enhanced whiteness about the terminator, such as that of fog particles floating in our morning and evening skies. This view is supported by the fact that the shading in question was not always present.

Everyone knows that *Venus* in quadrature shows not a dichotomous but a crescent phase. No one to my knowledge has found a satisfactory explanation of this phenomenon since Schrœter first called attention to it a hundred years ago. An attempt at an explanation was recently given by me,* namely, that it was due to the superior brightness of the limb, when the cusps would stand out " in noble relief, *through contrast and irradiation*, from the sombre central regions of the terminator." This is certainly so; but the interpretation given is not quite complete, and I am indebted for its full development to my friend, Abbé Moreux, whose theory may be summarised as follows :—

Let ABO (Fig. 3) stand for a quadrant of dichotomised *Venus*, OB the direction of the Sun, and CDEF the planet's atmosphere. The atmospheric illumination does not stop at DO but at CG. Towards OG we are looking on less atmospheric particles than at

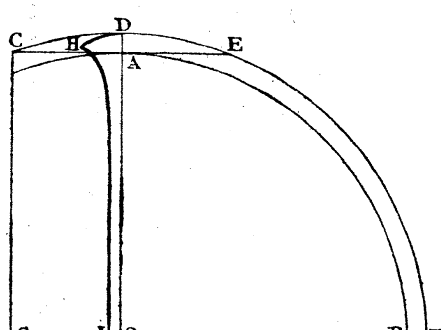

FIG. 3.

ADC where the luminosity is very considerably increased. Hence the final terminator curve will take a path such as DHI with a preponderance of brilliance at the exaggerated cusp H.

Owing to the great analogy of dimensions, we are fully justified in considering *Venus* as being the planet the most resembling our Earth. Now observation shows that the heights of

* *Journal of the British Astronomical Association*, vol. viii. No. 1.

the atmospheres of the two planets are also comparable, since that of *Venus* would measure, according to D'Abbadie, some 250 miles (2″ on a diameter of 62″·8 during the 1882 transit on the Sun), while that of the Earth extends from 190 to 212 miles, according to M. Liais, from observations on the influence of the highest regions of our atmosphere upon twilight at Rio Janeiro.* Here I think the comparison is not quite in favour of the height of the Earth's atmosphere, for if the excellent background of the corona cannot fail to show the slightest particles of the most rarefied regions of the atmosphere of *Venus*, we could not speak as confidently of the value of atmospheric heights based on twilight observations.

What the density of the atmosphere of *Venus* is we do not know, for we cannot rely on the discordant values of horizontal refraction (Schrœter 30′ 34″ ; Mædler 43′·7.)† It is probably not far different from our own. *Venus* receiving from the Sun an amount of heat per unit of area which is to what we enjoy as $\left(\frac{1}{\cdot 723}\right)^2 = \frac{1\cdot 91}{1}$, evaporation must be more active on this planet than on the Earth. But we should hesitate in assuming that the cytherean skies are usually overcast, for the reason that if the greater heat stimulates evaporation, the converse process of precipitation would be slackened for the same reason.

Applying to *Venus* Professor Langley's investigations on terrestrial atmospheric absorption, we should have the normally falling ray losing 40 per cent. of its intensity in its passage downward through the atmosphere. Of the 60 per cent. reaching the planet's surface less than one-quarter would be diffused by yellow sand itself, that is, 14 to 15 per cent.

And this quantity must lose again 40 per cent. in its return passage through the gaseous envelope. Thus no more than $\frac{1}{12}$th of the luminous rays ‡ would reach the eye of an observer placed in space. In spite of its apparent exiguity, this $\frac{1}{12}$th of the total radiation which we would see about the centre of the disc viewed along the radius vector, is a very considerable quantity, and one which would doubtless allow us to have a tolerably fair idea of the distribution of light and dark spots over the planet's surface, were it not for the supreme blurring cause—luminous diffusion from the planet's atmospheric particles. The effect of this diffusion is to reduce the contrast between the light and dark areas, to the utter blurring of the image.

Beneath its dazzling gaseous envelope, showing no more than some fugitive markings—at best functions of the phase—rotates the invisible globe of *Venus* in a period which is quite unknown. Terrestrial and Martian analogies, however, as well as the existence of some sort of relation between the masses of the planets and their rotation periods, would give to *Venus* a diurnal

* Moore's *Meteorology*, London, 1894, pp. 16–17.
† Chambers's *Descriptive Astronomy*, 3rd edition, p. 68.
‡ Flammarion, *La Planète Mars*, p. 89.

A A

rotation comparable to that of the Earth or *Mars*—a view supported by the great probability that the extraordinary results claimed by the long rotation could not reasonably have been brought about by tidal friction.

Long-enduring Spots on Jupiter. By A. Stanley Williams.

There are several cases on record of spots on *Jupiter* which have remained in existence for periods measured by a number of years. The first authentic instance of the kind relates to the celebrated spot which appeared in the latter half of the seventeenth century, and which may possibly be identical with the present well-known "red spot." This last-named object has been under constant observation for at least twenty years, whilst its existence can be traced for perhaps thirty or forty years more. A third instance is that of the brilliant white equatorial spot which attracted so much attention in 1880, and remained visible for at least five or six years. Such cases of extreme longevity are not only interesting in themselves, but are of extreme importance in connection with questions relating to the present physical condition of *Jupiter*.

The object of the present paper is to put on record another instance of remarkable longevity in a Jovian spot. The object in question was a brilliant white spot situated on the north edge of the great north equatorial belt. For convenience it is designated C. The following is a complete list of all the observed times of transit of this spot which have come to the writer's notice,* together with the corresponding longitudes, all uniformly expressed according to the "System II." of the late Mr. Marth's ephemerides for 1887 and 1888.† The zero meridian of this system has several times been subsequently shifted 10°, in order to make it correspond nearly with the centre of the red spot. The longitudes given here refer to the unshifted zero meridian. For the observations made by the writer, the weights attributed to them at the time have been added. These weights range from 1 (bad) to 5 (good). An additional column gives the brightness of the spot according to a uniform scale, in which eeB=most exceedingly bright, eB=exceedingly bright, vB=very bright, B=bright, mB=moderately bright, F=faint, vF=very faint, eF=exceedingly faint. The total number of transits is 153.

* The spot also appears in some of the Lick photographs of *Jupiter*, but it has not been thought necessary to measure these, the visual observations being already sufficiently numerous.

† The daily rate of rotation of this system is 870°·2700, corresponding to a period of rotation of $9^h\ 55^m\ 40^s{\cdot}63$.